Data Assimilation and Model Evaluation Experiment: North Atlantic Basin

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LONG-TERM GOALS

Long-term goals include the realization of an improved mesoscale prediction capability in the North Atlantic Basin, the development and distribution of associated model-derived and observed datasets, and the coupling of the resulting NAB model to regional-scale models of (e.g.) the New York Bight.

SCIENTIFIC/TECHNICAL OBJECTIVES

Modeling objectives are: (1) to produce a new generation of basin-scale ocean circulation models based on the spectral finite element technique; (2) to compare the performance of the resulting finite element model with that of more traditional ocean circulation models; (3) to couple the resulting basin-scale model to sub-basin-scale models for (e.g.) the coastal boundary layers; and (4) to apply the resulting nested suite of models to studies of regional dynamics and data assimilation. Present observational objectives are the development of selected data assimilation and validation datasets for the North Atlantic during the 1993 hindcast test period, including satellite AVHRR imagery, TOPEX altimetry and CTD/XBTs.

APPROACH

Available remote sensing and in situ datasets were acquired, processed and evaluated for use in DAMEE. These include AVHRR datasets from two sources, the Rutgers archive of locally acquired HRPT data and the recently available 1993 global Pathfinder dataset, TOPEX altimetric data generated at MIT for use in WOCE, and CTD/XBTs from the NODC global archive. Concurrent with the collection of these NAB datasets, we have developed a new oceanic general circulation model specifically designed for use within complex basin-to-global-scale geometries. Our model utilizes the spectral finite element method, in which the ocean is represented as an unstructured set of curved quadrilateral elements. The shape, size and layout of the elements is solely dictated by the geometry of the basin and the accuracy required. The solution is approximated with a high-order interpolant in each element, and the error is minimized by forcing the interpolation to satisfy the equations governing the flow, in this case the hydrostatic primitive equations.

TASKS COMPLETED: OBSERVATIONS

The analysis of North Atlantic data sets for assimilation and model evaluation continues with the emphasis shifted to 1993 based on previous Information Exchange Meetings.

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AVHRR Imagery - The full Atlantic was extracted from the high resolution (9 km), daily, ascending and descending Pathfinder images and separated into Level 3 (best) and Level 2 & 3 (good & best) data (1460 images total). The Rutgers archive was used to construct 1 km resolution subregions around the Gulf Stream, Florida Current and Loop Current for each available overpass using the same cloud detection algorithms and Level ranking (over 9,000 images total). Warmest pixel and patched composites were constructed over several intervals for analysis and assimilation. Gulf Stream images have been renavigated based on visible coastlines in preparation for the north wall analyses scheduled for this fall.

TOPEX Altimetry - A new TOPEX geoid for the western North Atlantic constructed by subtracting the Lozier climatology from a two-year altimetric mean. The geoid was validated in the Gulf Stream region via comparisons between the TOPEX-derived Gulf Stream maximum velocity axis and concurrent AVHRR-derived Gulf Stream north walls. Mean, standard deviation and envelopes for the TOPEX-derived maximum velocity axis were calculated. The new TOPEX results were compared to previous GEOSAT results. Individual files for the 1993 TOPEX tracks across the Gulf Stream have been prepared.

CTD/XBTs - A total of 13,058 casts for the North Atlantic were acquired from the Best category of the NODC archive of global CTD and XBT data. Beyond the usual search for obviously erroneous locations and data spikes, each CTD-derived temperature, salinity and density profile was plotted next to its nearest GDEM neighbor for evaluation. For each XBT, the nearest neighbor GDEM was used to construct a T-S relation so that temperature, salinity and density could again be plotted next to its nearest GDEM neighbor. Numerous bad points were discovered and cleaned up, resulting in 11,745 quality controlled casts (90% recovery) separated into daily files. The daily files were plotted to identify about 10 nearly-repeated east-west and north-south paths across the North Atlantic. Individual casts were regrouped into section files for each North Atlantic crossing and sorted by area. The corresponding GDEM-based section for each file was prepared for comparison. Statistical methods to compare the observed and climatological sections are being developed.

TASKS COMPLETED: MODELING

Implementation, execution, and evaluation of two independent sequences of North Atlantic Basin simulations has been initiated. The two models in use are the S-Coordinate Rutgers University Model (SCRUM) and the Spectral Element Ocean Model (SEOM). The former, a finite-difference-based model developed in part with ONR support (N00014-95-1-0457) and now in wide use, has been chosen for its traditional algorithmic design. The latter, a new model using unstructured horizontal grids and higher-order h-p-type finite elements, will be used to assess the potential advantages of these more novel methods.

SCRUM modeling - We have configured SCRUM for coarse-resolution studies in two separate domains. The former corresponds to the consensus DAMEE domain (6°N to 47°N at an average resolution of 0.5 degrees). The latter extends from 30°S to 65°N at an average resolution of 0.75 degrees, and has been chosen to more effectively limit the influences of open boundary conditions.

Multi-year sensitivity studies have now been conducted in both the 0.5- and 0.75-degree configurations, with the intent of understanding the mutual effects of topographic smoothing and levels of subgridscale dissipation. We have found that the model is sensitive to the details of the bathymetry smoothing and produces unacceptably noisy fields when the isobaths intersect the land mask. As a consequence, alternate automated topographic smoothing algorithms have been implemented and assessed. None is found to be completely satisfactory, and much manual intervention is currently needed at these coarse resolutions to produce reasonable bathymetries, particularly near continental boundaries, within shallow seas, and through narrow passages.

Though the degree of realism of these simulations is a strong function of bathymetry and subgrid-scale parameterization, we find that the greatest degree of model improvement is associated with the repositioning of the model boundaries to 30°S and 65°N. Even with its lower overall resolution (0.75 degree), the larger domain model produces considerably more realistic indices of basin-scale circulation, including those relating to location of the Gulf Stream front, intensity of the Deep Western Boundary Current, and deep water formation rates. This suggests to us that the choice of the smaller domain for DAMEE/NAB will complicate model intercomparison.

SEOM modeling - The shallow water version of the SEOM (Iskandarani et al, 1994) has now been extended to three spatial dimensions. Two alternative forms of 3D SEOM are currently available: a first based upon a layered vertical representation, and a second which solves the continuously stratified, hydrostatic primitive equations. The former of these 3D versions is not in active use for DAMEE/NAB, though it is being applied to coupled basin-scale/coastal circulation studies in support of U.S. GLOBEC programs in both Georges Bank and the Northeast Pacific.

The past year has seen extensive intercomparison of the continuously stratified SEOM model with several more traditional circulation models including the Miami Isopycnic Coordinate Model (MICOM), the GFDL Modular Ocean Model (MOM), and our own s-coordinate model (SCRUM). The basis for this comparison has been a set of analytic and semi-analytic test problems which we have been collecting and refining for some time. Tests problems in this suite include the propagation of a non-linear Rossby soliton, flow around a tall seamount, adjustment of a gravitationally unstable density front, boundary currents along an inclined western boundary, and wind-driven flow over a steep coastal canyon. An extensive summary of these tests is being prepared for publication as part of a book-length summary of numerical ocean circulation modeling (Haidvogel and Beckmann, 1998).

Fortunately, our ability to automatically generate unstructured quadrilateral grids has taken a large step forward this year. An automated finite element gridding package (CUBIT), obtained from Sandia National Laboratories, has been successfully interfaced with our own coastline database tools.

SEOM is presently being readied for a head-to-head comparison with SCRUM in the 0.75-degree North Atlantic configuration.

RESULTS

AVHRR Imagery - Cloud detection algorithms for Level 3 AVHRR data also mistakenly lose fronts and coastal regions. Many of these features reappear in the Level 2 & 3 data with some cloud leakage. The biggest problem with Pathfinder cloud detection algorithms appears to be the climatology comparison, which was turned off in the reprocessed Rutgers images but must be accepted in the Pathfinder data. Day-night differences between subsequent Pathfinder images were found to be greater than differences between subsequent days or subsequent nights.

TOPEX Altimetry - The separation between the altimeter-derived Gulf Stream maximum velocity axis and the AVHRR-derived north wall averages 17.9 km for TOPEX and 17.3 km for GEOSAT, with the separation in both cases similarly modulated by Stream curvature. The TOPEX mean Gulf Stream path is very similar to GEOSAT west of 66°W, but east of this location, the TOPEX mean is shifted approximately 50 km northward. Relative to the mean, the TOPEX and GEOSAT standard deviations have similar widths, indicating that the typical meander structure remained the same despite the northward shift. The TOPEX envelope, however, is wider on the north side, while the GEOSAT envelope is wider on the south side due to the preferential absorption of warm or cold rings.

CTD/XBTs - The numerous near-repeat sections across the North Atlantic along shipping routes provide good resolution of the thermocline as it varies across the basin at different locations over the seasons. The Straits of Florida to Straits of Gibraltar section is one of the most informative, indicating that the yearly warming and cooling cycle for the North Atlantic actually begins and ends sometime in February/March, not January 1. Concurrent model and XBT sections could be used for model validation in two ways. The differences between the model and observed temperatures at selected depths could be calculated to produce profiles of average error statistics similar to the CIMREP evaluation of TOPS and MODAS. A second approach would be to compare the depth of a specific isotherm used to define a specific feature like the seasonal thermocline or the 18° Sargasso water.

Modeling - Operational versions of the Spectral Element Ocean Model in both two and three spatial dimensions are now available. Analytic and semi-analytic test problems confirm model performance - e.g., its faster-than-algebraic convergence (Taylor et al., 1997). Decadal-length simulations of the wind-driven circulation on global, unstructured grids have been conducted which demonstrate readiness for realistic basin-scale applications (Haidvogel et al., 1997). Parallel performance of the 2D model has been assessed, with extremely favorable results (Curchitser et al., 1997). High-order spectral filters have been developed to avoid non-linear instability in the presence of turbulent jets and eddies; wind-driven simulations of Gulf Stream meandering and ring generation have shown that as few as two gridpoints per Rossby radius can capture the asymptotic fields of (e.g.) eddy kinetic energy in the reduced gravity limit (Levin et al., 1997).

IMPACTS

As in DAMEE-GSR, the oceanographic and topographic datasets developed under this project are critical to the data assimilation studies planned for DAMEE-NAB. The numerical model is unique in DAMEE-NAB, providing a global capability with efficient multi-scale resolution in regions of interest using unstructured grids on high performance computers.

Specific observational issues affecting DAMEE include:

AVHRR Imagery - Image composites for assimilation should be constructed using all day or all night images, but not both to avoid the formation of spurious fronts caused by large day/night differences.

TOPEX Altimetry - The only comparisons between concurrent altimetric-derived Gulf Stream maximum velocity axes and AVHRR-derived north walls in the published literature indicates that both the GEOSAT and the TOPEX altimeter consistently observed a maximum velocity axis about 18 km south of the north wall, half the distance of previously published distances. The planned 1993 North Atlantic hindcast should produce a Gulf Stream with a more northern mean location that entrains more warm core rings.

CTD/XBTs - The planned January to December 1993 hindcast will include the final cooling for the 1992 cycle, and will end before the 1993 cycle is complete. Extending the 1993 hindcast through February of 1994 to complete the 1993 cycle should be considered.

TRANSITIONS EXPECTED

Basin-scale datasets, models, and data assimilation procedures will be transitioned to operational use as a consequence of the DAMEE/NAB effort. All observational datasets have been made available to DAMEE participants via anonymous ftp to Rutgers and by transfer to the DAMEE archive maintained by USM.

RELATIONSHIP TO OTHER PROJECTS

The basin-scale modeling capability being implemented and tested under DAMEE/NAB will be used to provide the basin-scale context and coupling to two regional coastal observation/modeling programs. The first, the Rutgers University Coastal Ocean Modeling and Observation Program (COMOP), has as its general objective the understanding and real-time modeling of sediment transport and upwelling frontal dynamics in the New York Bight. The COMOP studies are jointly funded by ONR/NOMP and NOAA/NURP. The second involve the establishment of a coupled coastal/ basin-scale modeling capability for Georges Bank. These latter studies are funded by NSF. The SEOM model developed under this project also is being used to study sediment transport in the Newark Bay in a New Jersey sponsored project.

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